WARM-MIX ASPHALT FOR AIRFIELD PAVEMENTS

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ABSTRACT

This paper describes an evaluation program conducted by the US Army Engineer Research and Development Center to determine the suitability of using warm-mix asphalt (WMA) technologies for airfield pavements. The work consisted of two main phases. Phase I consisted of laboratory evaluations of the performance of different WMA technologies and included tests for rutting, durability, low-temperature cracking, moisture damage, binder properties, and workability. Phase II consisted of evaluating production and placement procedures and conducting accelerated pavement testing on full-scale test sections under simulated full-scale military aircraft traffic to evaluate rutting performance. In both phases the performance of mixtures produced using different WMA technologies was compared to that of the same mixtures produced at hot-mix asphalt (HMA) temperatures. WMA was recommended as a viable alternative to HMA for use on heavily trafficked airfield pavements. The Unified Facilities Guide Specification (UFGS) 32 12 15.16 was developed along with two Engineer Technical Letters (ETL) to provide guidance for using WMA on airfield pavements.

INTRODUCTION

The hot-mix asphalt (HMA) industry seeks emerging technologies that reduce environmental impact during production of bituminous paving materials (Figure 1). In recent years, warm-mix asphalt (WMA) has replaced HMA for many paving projects. WMA is a general description for asphalt concrete that is produced at lower temperatures than conventional HMA while maintaining the same level of workability. Many techniques have been developed to produce WMA, including chemical additives, organic wax additives, and foaming. Many state departments of transportation (DOTs) are quickly adopting WMA for roadway paving, and many are using it in place of conventional HMA. As the states' DOTs gain experience with WMA, conventional HMA may become less available for paving.

Figure 1. Emissions from HMA vs. WMA [1].

Empirical evidence has indicated that WMA performs well on highways. However, very little research has been conducted to assess the potential of WMA for being adopted for airfield paving projects. The airfield pavements community lacks guidance and requires more experience with these technologies. It is important to highlight the difference between highway and airfield pavements to understand the need for specific research for determining the suitability of WMA technologies for airfield pavements.

The main differences in design considerations for highway and airport pavements arise from the characteristics of the traffic using them such as load repetitions and distribution, the magnitude of the loads, and the tire pressures. Over its typical design life span, a highway pavement receives millions of channelized wheel load applications. The effects of load repetitions such as cumulative permanent deformation, crack propagation, and fatigue failure need to be considered. Therefore, the total number of load applications in the entire design life of a highway pavement is required for its structural design. In contrast, the frequency of aircraft loading on airfield pavement is much less. The wander effect of aircraft landing and taking off and the large variation in the wheel assembly configurations of different aircraft make wheel loading on airport pavements less channelized than on highway pavements. Therefore, identifying the most critical aircraft is necessary for structural design of airfield pavements.

Another important difference is in the magnitude of wheel loads. Airfield pavements receive loads far exceeding those applied on the highway. The maximum single wheel load allowed on the road pavement by most highway authorities ranges from 4,000 to 5,000 lb, whereas airfield pavements must support tire loads as high as 50,000 - 60,000 lb. Moreover, a wheel tire pressure of an aircraft of about 250 psi is more than twice the value of a normal truck tire. These differences greatly influence the material requirements for pavement design and clearly justify the need for developing specific guidance on the use of WMA for airfield pavements.

WMA RESEARCH

The lack of guidance on the use of WMA for airfield pavements and the need to study the rutting performance of WMA under high tire pressures and heavy aircraft loads led the Air Force Civil Engineer Center (AFCEC) to fund a research program at the US Army Engineer Research and Development Center (ERDC) in Vicksburg, MS, to evaluate WMA technologies for airfield pavements. The program focused on evaluating mix production and placement procedures and laboratory and field performance of WMA pavements. All these aspects of WMA pavements were compared to those of HMA pavements.

Phase I: Laboratory Evaluation

This phase included evaluation of the three main categories of WMA technologies: chemical additives, organic additives, and foaming agents or processes. The laboratory performance of different WMA technologies within these categories was compared to the performance of the same mixtures produced at HMA temperatures. Properties assessed included binder properties, susceptibility to rutting, moisture damage, and low-temperature cracking; durability; and workability [2-6]. In one portion of this phase, the use of reclaimed asphalt pavement (RAP) was evaluated to study the incorporation of higher percentages of RAP in WMA than what is allowed in HMA [2]. The use of different types of test specimens was also evaluated to determine any effects on performance. These included laboratory-produced-laboratory-compacted (LPLC), plant-produced-laboratory-compacted (PPLC), and plant-produced-field-compacted (PPFC) [5-6]. Additionally, PPFC specimens were obtained at different times after pavement construction to monitor rutting performance with time. Table 1 lists the test methods used in the laboratory.

Table 1.
Laboratory Performance Tests.

Property	Test	Standard Method/ Reference
Rutting	Asphalt Pavement Analyzer (APA)	AASHTO T 340
	Hamburg Loaded Wheel Tracker	AASHTO T 324
	Flow Time	Witczak (2002) [7]
	Flow Number	Witczak (2002) [7]
	Dynamic Modulus	AASHTO TP 62
Moisture Damage	Tensile Strength Ratio (TSR)	AASHTO T 283
Low-Temperature Cracking	Bending Beam Rheometer (BBR)	AASHTO T 313
Durability	Cantabro Test	Doyle and Howard (2011) [8]
Workability	Torque Method	Mejías-Santiago (2014) [9]
Binder Properties	Performance Graded Asphalt Binder	AASHTO M 320

UFGS 32 12 15.16 [10] requires a minimum TSR value of 75% and this is shown as a horizontal line in Figure 2. This figure shows that WMA has somewhat higher susceptibility to moisture damage than comparative HMA. However, increasing the production and compaction temperatures increases the TSR [3]. Therefore, part of the reduction in TSR observed in WMA mixes can be attributed to the temperature difference between WMA and HMA. RAP decreases the moisture susceptibility of both WMA and HMA [3].

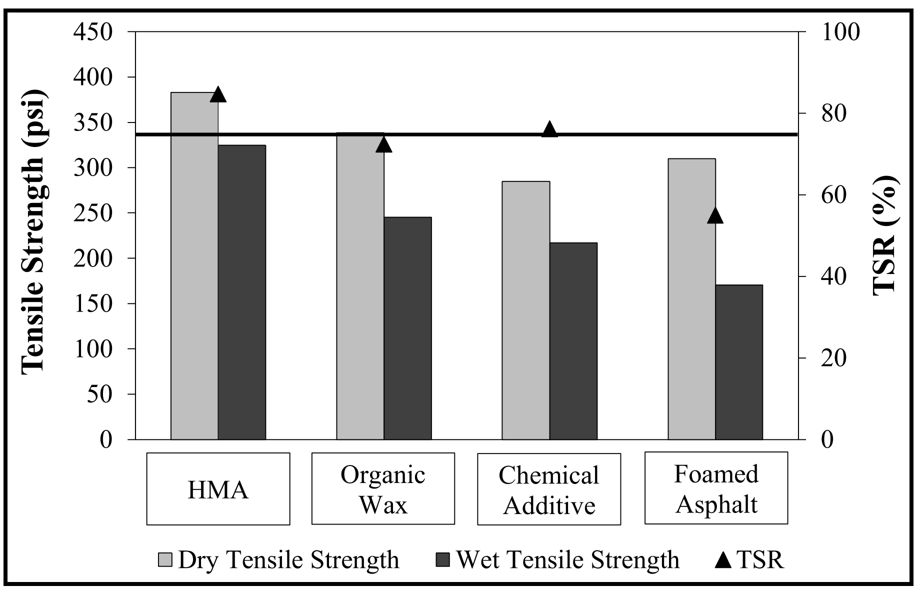

Figure 2. Tensile Strength and TSR Results from Laboratory Mixes.

WMA may initially have somewhat greater susceptibility to rutting than comparative HMA due to reduced aging of the binder during production. However, WMA will match or exceed the initial performance of comparative HMA after a reasonably short curing period. The category of

WMA technology (i.e., chemical additive, organic additive, or foaming process) was not generally indicative of rutting performance. The use of RAP increased the laboratory rutting resistance of both WMA and HMA. Figure 3 shows APA results from WMA and HMA laboratory and field mixes for comparison. The horizontal line represents a threshold criterion of a minimum 4,000 cycles to achieve 0.4 in. of rutting for airfield mix acceptance with the use of a 250-lb wheel load and 250-psi hose pressure on 4% air void specimens recommended by [11].

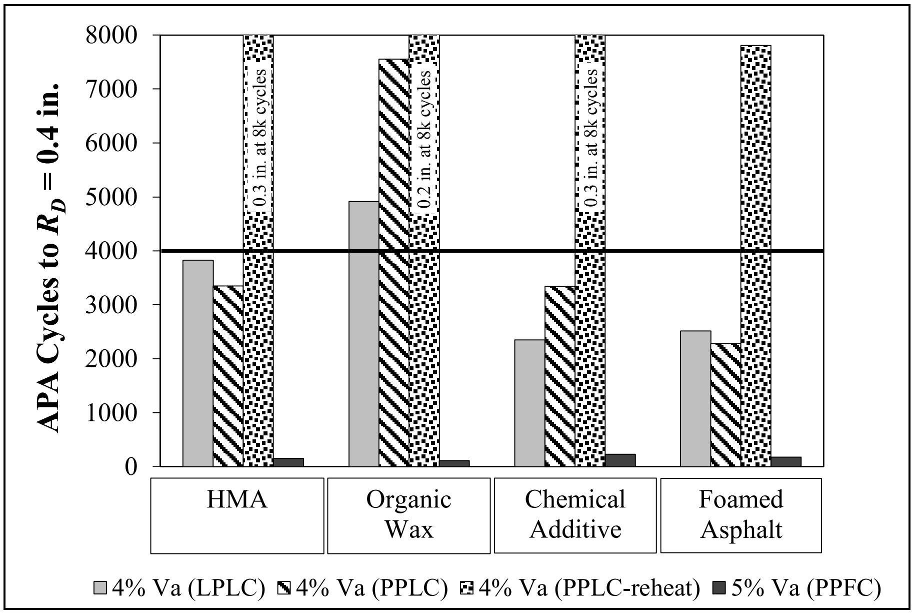

Figure 3. APA Rutting Results from Laboratory and Field Mixes.

Susceptibility to thermal cracking is not believed to be a concern for WMA [2]. In terms of durability, no statistically significant differences were found between HMA and WMA or between WMA technologies [2]. Also, WMA proved to have better workability than HMA at lower temperatures. The addition of high percentages of RAP to WMA mixes can increase their susceptibility to thermal cracking, create durability issues, and reduce workability. However, high-RAP WMA mixes still have better workability than high-RAP HMA mixes [4].

Low Performance Grade (PG) temperature data from binder testing did not show significant performance reductions associated to the use of WMA. High PG temperature data do not suggest that rutting performance will be detrimentally affected by the use of WMA additives. The use of high RAP contents causes a noticeable increase in rutting resistance but only a limited increase in thermal cracking susceptibility [4].

Comparing test data from different specimen types provided information on how performance tests could be sensitive to specimen type. Results from LPLC mixture indicated a somewhat reduced mixture stiffness and greater rutting and moisture damage potential for WMA relative to HMA. However, data for PPLC WMA mixtures, with and without reheating, generally indicated similar mixture stiffness, rutting performance, and resistance to moisture damage to HMA. All PPFC mixtures, WMA and HMA, had very poor APA rutting performance compared to PPLC mixtures. This indicates that performance test protocols need to be established for field-compacted specimens to ensure quality assurance testing accurately reflects in-service pavement conditions [6].

Phase II: Field Evaluation

Mix Production and Placement Procedures

WMA production and construction procedures were evaluated to compare with those used for conventional HMA. Three WMA technologies (one chemical additive, one organic additive, and one foaming process) were used. Data collected included moisture content, time from production to placement, any special equipment requirement, temperature of the mixture during paving and compaction, density of the asphalt layer during compaction, and the number and type of roller passes required to achieve adequate mat density.

A single aggregate blend was designed for the three WMA mixes and the HMA control mix. The blend was designed to meet Job Mix Formula gradation requirements for a 0.5-in. nominal maximum aggregate size mixture according to DoD UFGS 32 12 15.16 [10]. The blend consisted of 60% limestone, 25% crushed gravel, and 15% natural sand (maximum allowed by specification). The aggregate sources and blend were selected based on materials available for plant production. The four asphalt mixtures were designed with 75 gyrations in the Superpave Gyratory Compactor in accordance with UFGS 32 12 15.16 [10] requirements. Target volumetric properties were air voids (V_a) of 4% and minimum voids in mineral aggregate (VMA) of 14.0%.

The asphalt supplier was able to provide the HMA and WMA using the same production equipment. Procedures for producing each mixture were the same in terms of plant operations. The only unique requirement for WMA was supplying the additive. The chemical additive was pre-blended with the binder at the asphalt supplier's terminal and did not require any special equipment. The organic wax and foamed asphalt required an external feed source to inject the additive or water into the mixing drum.

The procedures for placing and compacting the WMA were similar to those used for the HMA. Although the mixture was delivered at a lower temperature, the rolling pattern was very similar for HMA and WMA. The WMA additives appeared to provide additional workability at lower temperatures to allow for sufficient compaction of the mixtures.

The procedures for evaluating material properties during QC or QA were not impacted by the use of WMA. Volumetric properties should be determined the same way as traditionally measured for HMA. The design V_a and VMA could be achieved with WMA produced at full scale. Neither the addition of moisture nor the production of the mixture at lower temperature caused excessive moisture to remain in the mixture. In fact, moisture tests on the mixtures indicated they had only about 25 percent of the allowable maximum moisture of 0.5 percent [10].

WMA was produced, placed, and compacted at temperatures 20-30^{o}F lower than an HMA (Figure 4) using the same aggregate, while achieving equivalent density using the typical 2-in. lift thickness.

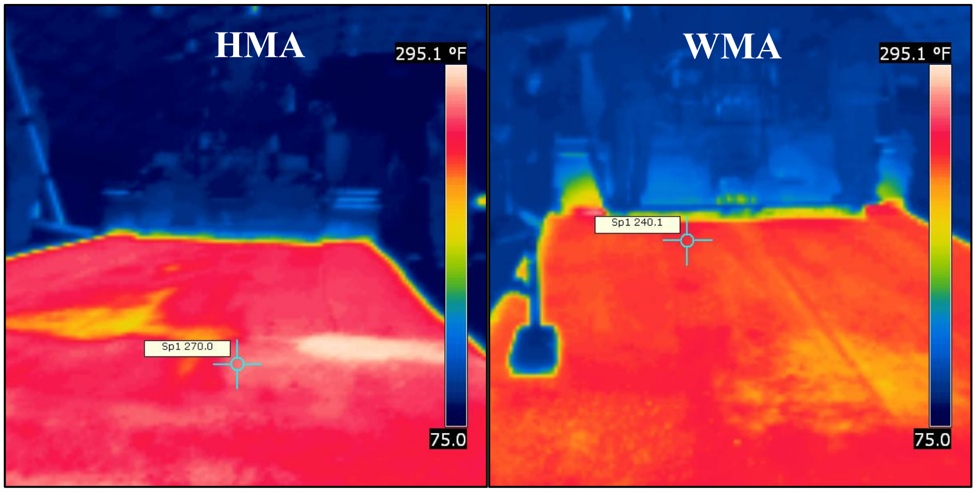

Figure 4. Temperature Difference between HMA and WMA During Placement.

Accelerated Pavement Testing

The flexible pavement test section was designed in accordance with DoD requirements for structural design of medium-load United States Air Force (USAF) airfields [12]. The pavement structure was designed with the intent of minimizing deformation in the unbound granular layers so that failure would occur predominantly in the asphalt surface layer. The test section was divided into four test items; design layer thicknesses and unbound granular material properties were consistent throughout. A dense-graded HMA mix was used in the control test item, and three different types of WMA technologies were used in the other three test items: a chemical additive, an organic wax additive, and an asphalt foaming process. The test section was constructed under shelter in the ERDC's Accelerated Pavement Testing Facility. Additional details on the design and construction of the test section can be found in [13-14].

Each item was instrumented to measure the pavement response to simulated aircraft loading. Data collection included permanent deformation, earth pressure distribution, individual layer deflections, strains at the surface and at the bottom of the asphalt layer, pavement and air temperatures, and deflections from the falling weight deflectometer (FWD) test. A combination of worst case loading conditions and high pavement temperature was applied to the flexible pavement under study to induce rutting failure in the asphalt layer. The F-15E military fighter jet aircraft was selected for accelerated traffic simulation because of its small footprint and high tire pressure of 325 psi, which results in very high stresses near the pavement surface, producing an aggressive effect on the asphalt layer. A test temperature of 109ºF was selected, as it is the Witczak [15] effective test temperature for Jackson, MS. Effective temperature is a single test temperature at which an amount of a given type of distress, within a given pavement system, would be equivalent to that which would occur from the seasonal temperature fluctuation throughout the annual temperature cycle.

Each test item was trafficked in a bi-directional, normally distributed traffic pattern using a heavy vehicle simulator (HVS-A). The HVS-A is a fully automated machine that simulates accelerated aircraft traffic on pavement test sections while allowing control of the pavement temperature with an integrated climate control system (Figure 5).

Figure 5. Overview and Inside View of the HVS-A.

FWD and pavement response data showed no movement or changes in the pavement sublayers due to traffic. This successfully demonstrated that the rutting performances of the four test items were not influenced by the structural capacity of the pavement sublayers, but only by the capacity and properties of the surface asphalt mix [16]. Furthermore, forensic investigations conducted after traffic to inspect the integrity of the pavement substructure confirmed that no movement was experienced by any of the pavement sublayers. Figure 6 presents a typical trench with the rutted asphalt pavement over intact pavement sublayers. The pronounced uplift of material on both edges of the trafficked area is indicative of shear flow of the asphalt mixture.

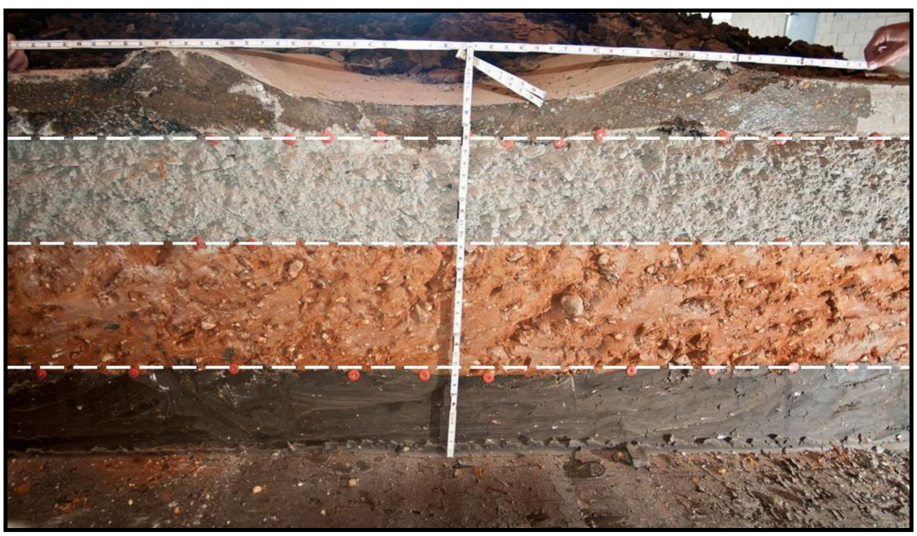

Figure 6. Typical Rutted Asphalt over Intact Pavement Substructure after Traffic.

Field rutting performance results were mixed due to a combination of factors, including a test temperature variation between test items and a difference in the time when the items were tested after construction. Two of the three WMA mixes, the chemical and the organic additives, had slightly lower rutting resistance than the HMA mix. The third WMA mix, foamed asphalt, outperformed the HMA by requiring more than double the number of passes to failure. However, on average WMA mixtures had rutting resistance similar to that of the HMA mixture (Figure 7).

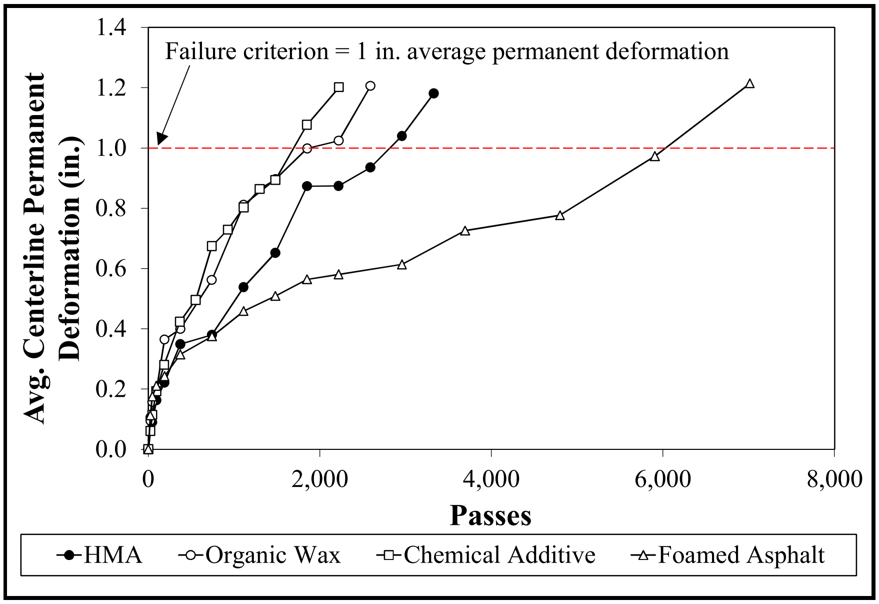

Figure 7. Rutting Results from Accelerated Pavement Testing.

SUMMARY AND CONCLUSIONS

In summary, the laboratory evaluation results showed that WMA could perform similar to, or better than, comparative HMA. WMA can be produced, placed, and compacted at temperatures 20-30^{o}F lower than an HMA using the same aggregate, while achieving equivalent density using the typical 2-in. lift thickness. Field rutting performance results showed that on average WMA mixtures had rutting resistance similar to that of the HMA mixture. WMA was therefore recommended as a viable alternative to HMA for use on heavily trafficked airfield pavements.

TECHNOLOGY TRANSFER

Two Air Force engineering technical letters (ETLs) and one UFGS were developed from this research. The first, ETL 11-3, was published in August 2011 and provided general information and guidance on WMA technologies. The UFGS 32 12 15.16 was published in 2012 and provided more specific guidance on construction of airfield pavements using WMA. The second ETL, under review, highlights the most important aspects of the specifications. These documents are available in the Construction Criteria Base of the Whole Building Design Guide: http://www.wbdg.org/ccb/ccb.php.

FUTURE WORK

Long-term performance of WMA compared to HMA should be documented through trial sections placed on active military airfields. Both HMA and WMA mixtures utilizing the same source materials should be placed and their performance monitored for at least two years.

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